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START and Stability

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Abstract

In this study, which extends our investigations of prevenient stability, we examine the effects of strategic arms reductions such as those proposed in the Strategic Arms Reduction Talks (START). We use exchange models and the theory of prevenient stability to look at the changes in crisis stability and deterrence that would be brought about by future cuts in the strategic nuclear forces of the US and the USSR. Our analysis includes strategic defenses and hypothetical technological breakthroughs. Our results indicate that, if force vulnerabilities exist on either side, arms reductions would erode deterrence—the greater the degree of vulnerability, the greater the effect. Defense of strategic strike forces, if perfected, would improve deterrence and increase crisis stability. Otherwise, it is clear that prevenient stability, as explicitly defined herein, would be decreased.

I. Introduction

The apparent liberalization and restructuring now taking place in the Soviet Union lead most people to believe that a strategic arms reduction treaty (START) in some form will soon be a reality. In itself, that belief will influence foreign policy and military budgets almost as much as an actual agreement would. We are already beginning to see the formation of a consensus that less reliance on nuclear arms will be the way of the future, and we may be about to experience an era of unprecedented reductions in nuclear weapons stockpiles and delivery systems. This study was undertaken to analyze the changes in stability that can be expected if such reductions do occur.

Many aspects of the old strategic dogma, if not ideal, were at least tolerable. Somehow, in a world where armed conflict was commonplace, no serious blood-letting occurred between the Warsaw Treaty Organization (WTO, or Warsaw Pact) and NATO. The massive nuclear capabilities of the Soviet Union and the United States were never brought into action. On the eve of change, then, it is wise to address several concerns. We should be alert to the possibility that the new nuclear epoch may not be entirely without its own new and troublesome aspects. Four areas suggest themselves immediately.

First, let us consider the old concepts of stability and deterrence and how they will be impacted by reductions that will cause nuclear forces to be less than half the size strategists have learned to rely on and to fear. If it is true today that, for all intents and purposes, we have enough weapons to consider that half of them (or more) are indeed superfluous, will the future not require a redoubled effort to define how much is really enough? As repugnant as mutual assured destruction (MAD) may be, we still need to ask if the concept of deterrence will be sufficiently operative in the future. That is, we need to quantify and compare the status quo and the situation that may come into existence under START.

Second, in a similar way, we must worry to some extent about numerology and technology. Historically, scientific and engineering developments have worked to render weapon systems vulnerable or obsolete. Is this a concern in the START era? Is it feasible that arsenals already halved by legislation may be seriously threatened by new technologies? What quantifiable changes can we expect in the stability equations to which we have been accustomed for so long? We need to perform some calculations to gain confidence as to how important these effects may be and how much effort will be justified to insure against technological surprise.

Third, it seems to go without saying that START redefines the current wisdom regarding active strategic defense. With a semi-infinite number of nuclear warheads available to overwhelm any given defended sector, the offense had an advantage that was difficult for even the most sophisticated defensive scheme to offset. In the past, such considerations tended to cause delay and confusion. Will future arms reductions make it possible to achieve a scientific and political consensus for the Strategic Defense Initiative (SDI)? Again, some calculations are in order. We need to know how much we can accomplish with defenses of any given effectiveness.

Fourth, if START does indeed become a reality, we will soon see pressure from two groups: one, believing that START is not in the best interests of the United States, will seek a return to the current posture. From the comparison we have made between START and the status quo, we will be better prepared to assess the merit of their arguments. However, it is far more likely, given the circumstances that would apply under START, that another, more influential group would see the apparent wisdom in further reductions. Thus, possibly even before strategists have fully recognized the implications of drastically reduced nuclear armaments, they may be asked to construct doctrine based on even fewer weapons. Instead of a few tens of thousands of nuclear warheads we may be dealing with a few thousand, possibly even a few hundred. We need to look into the crystal ball to predict what rewards and what pitfalls lie in future reductions beyond START.

Our intent is to cast some light on these questions by using analytic techniques described and used extensively in the past; namely, the algorithms contained in the computer code EXCHANGE 8.7. We give a brief, nontechnical description of this code in Section III—brief and nontechnical because the references on the subject are exhaustive, and the logic of EXCHANGE 8.7 is straightforward.[1,2]

However, we take an approach that is slightly different from our past analyses. In Section II, we examine the physical aspects of stability and deterrence, creating the logical framework for detailed analysis in such a way that the reader can understand the general nature of change without reference to the results of the code. The interplay of stability and deterrence (what we have previously referred to as "prevenient stability"[3]) is tied to the damage anticipated in a nuclear war, or "exchange." How the damage to societal values depends on numbers of targets and weapons and on opposing strategies is explained in a semi-quantitative manner. More important, the actions the two sides can take to reduce anticipated damage becomes clear, and it is seen that therein lies the root of instability in the physical sense.

Moving on from this formulation, in Section III we undertake some detailed analysis. The bulk of Section III deals with the analysis used to illuminate the four areas we feel merit investigation. There we describe the exchange code used and define the input data needed and the output, or result, of an exchange. Then, in the first set of calculations, we compare the strategic exchanges that might take place now with those to be expected under START. Since far-reaching assumptions must be made in defining the opposing forces under START, these are explained and justified, and a number of variations to force structures are examined.

In investigating the effects of new technology and SDI, we use this same base-case START scenario. For the issue of new technology and the potential vulnerabilities associated therewith, we bound the problem by assuming that various US strategic systems simply become inoperative, and we compare subsequent exchanges with the base case. SDI is simulated by reducing the vulnerability of US forces and value elements a degree at a time so as to offer the reader a chance to determine in his own mind how much defense is justified.

The question of what lies beyond START is handled by assuming that START levels are once again halved, but we do not try to anticipate changes in the nature of the strategic forces so far in the future. That is, we use the same types of forces as in the base-case START scenario, and simply halve the numbers of weapons and strategic nuclear delivery vehicles (SNDVs) on both sides.

The results of these four sets of analyses are tabulated and discussed on a case-by-case basis. Many of the exchanges are essentially limiting cases that need to be heavily caveated, and this is done. Wherever it seems useful, the detailed results are placed in the context of the less mathematical discussion given in Section II.

Section IV is a brief attempt to draw some useful and general conclusions from the mass of data. Despite the analytical rigor of EXCHANGE 8.7, the input to each exchange is open to choice. Any analyst can use the same code to run the same general type of problem by substituting the forces and vulnerabilities he feels to be most appropriate, thereby testing our conclusions. It is clearly impossible to examine all probable variations in input data. On the other hand, it would not be constructive to describe all the variations actually made that had little resulting change associated with them. We do claim that the conclusions of Section IV apply generally as prudent considerations for future action regarding US/USSR efforts toward stability and mutual security.

II. Physical Aspects of Stability

SALT and START

For some time now, the US and the USSR have lived with nuclear arsenals that were shaped, capped, or at least influenced by agreements on arms limitations. Because nations are slow to respond to change, it is prudent, on the eve of a new arms-reduction treaty, to cast a backward look.

Almost two decades ago, in May 1972, the US and the USSR signed a formal agreement to limit strategic offensive arms. Long referred to as SALT I (for Strategic Arms Limitation Talks) this agreement took on the nature of a treaty to many, and indeed it was given a permanence beyond its 5-year term by the announcement of SALT II in November 1972. In the case of SALT II, the last initial of the acronym SALT eventually came to stand for the word "treaty," in view of the joint signing of the "Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Limitation of Strategic Offensive Arms" by President Jimmy Carter and General Secretary Leonid Brezhnev in Vienna on June 18, 1978.[3]

The use of the word "treaty" with regard to SALT II is certainly not justified in the legal sense because it was never ratified by the US Senate. Indeed, President Reagan chose not to present SALT II for ratification, as he had previously referred to it as "fatally flawed." With the inconsistency that marked most US/USSR interactions, however, both Reagan and Brezhnev gave assurances of their intent not to jeopardize the "treaty" as long as the other side did not violate its terms. In fact, both sides have maintained forces quite similar in quantity to those defined in SALT II, consistent with the need for technological modernization and replacement.

In a sense, the recent history of strategic arms negotiations can be termed successful in the spirit of the original SALT I accords, in which it was intended to first limit and then reduce strategic arms. In the past few years, considerable momentum for strategic arms reduction has accumulated, and a draft Strategic Arms Reduction Treaty is under continuing and cooperative review by both sides.[4] Many detailed provisions of the treaty have not as yet been agreed upon, and others have not been released to the public. The intent, however, is to approximately halve strategic forces over the eight years following ratification of the treaty.

Stated so flatly, this is a development of enormous impact in the strategic relations between the two sides. Despite the fact that START has no legal existence at this writing, its impact on the affairs of the United States is real and profound. A reduction so large taking place over a relatively few years has already channeled the thinking of legislative and defense staffs in the direction of what forces are to be reduced and how strategic doctrine will be changed. The case can be made that START is already changing US strategic force posture and strategy.

START and Change

In the past, we have developed a structural logic that we have used from time to time to evaluate actual and proposed changes to strategic offensive and defensive forces.[6] Our thinking has been based on the concept that, given the strategic offensive and defensive nuclear arsenals available to the US and the USSR, the incentive of either side to initiate nuclear war ("first strike") is a prime subject for examination when any change to the present nuclear force structure is proposed.

For more than a quarter of a century, general and complete disarmament has been the stated goal of US diplomatic policy. Today, it is clear that the nuclear postures envisioned under

START will be roughly halfway between where we are today and that goal. To some, progress is glacially slow, but a START agreement appears to be close at hand. Change in Europe and the USSR is moving at a pace not seen for decades, and most people view recent events with cautious optimism.

Our concern centers on the lack of analysis we perceive to exist regarding the effects of change on prevenient stability. We have seen in the past that changes in strategic postures bring about changes in first-strike incentives that most analysts would agree are often counter-intuitive. Much as most arms-control experts would deny their personal acceptance of such an all-encompassing statement, a general "theology" exists regarding nuclear weapons to the effect that more is necessarily bad (evil) and less is necessarily good. Similarly, stability (in the analytical sense of prevenient stability) also appears to be independent of arbitrary standards; that is, no one will stand up to explicitly make the case for "less stability" (i.e., state a preference for greater incentives to initiate nuclear war by a damage-limiting first strike). Unfortunately, fewer weapons and stability are not necessarily compatible.

Therefore, the need to investigate *all* potential results of agreements as far-reaching as START is incumbent on the arms-control community. This is not to say that each and every aspect of negotiated change must be positive for the negotiations to be acceptable. Not at all. However, as we demonstrate in the following sections, START has certain negative aspects that should be clearly recognized in order to limit or eliminate their potential adverse consequences and so that they may serve as focal points for subsequent negotiations.

Formulation of the Problem

Since both the US and the USSR have agreed by treaty that they are "proceeding from the premise that nuclear war would have devastating consequences for all mankind,"[3] it is reasonable to develop the logical chain of events that might conceivably drive one side to initiate such devastation. It can be difficult, given this premise, to explain how the nuclear weapon stockpiles of the two sides attained their present size. The kernel of the utility of a counterforce first strike has an even longer history than the formal US/USSR recognition of the potential consequences. It stems from the belief that, under some combination of circumstances, a nation would do better to initiate hostilities than to await an enemy first strike. This notion, in turn, depends on the first-strike nation's ability to somehow limit the damage that can be done in the retaliatory strike.

Conceptually, we can use Fig. 1 to define our terms in visualizing the rudiments of the thought process of the strategic thinker who, for whatever reason, rational or not, contemplates a damage-limiting first strike. From the standpoint that a nuclear exchange is assumed to take place, he thinks in terms of a few simple variables. Basically, he is concerned with the number of weapons his side will actually deliver on the enemy ($N_1 + N_2$) and, likewise, the number that will be available for use in the retaliatory strike (N_3). A prime motivation will be to reduce N_3 insofar as he is able. To this end, he should plan to use some number of weapons (N_1) to attack his opponent's vulnerable SNDVs. Presumably, N_3 will be reduced in proportion to N_1, according to the degree of vulnerability of his opponent as well as the degree of effectiveness of his own counterforce assets. But, of course, his cerebrations cannot stop at this point—he will have to consider the overall consequences of his actions.

Unless our hypothetical planner has incontrovertible proof that N_3 will be zero or that there will be no retaliation, he must consider the relative positions of the two sides after the exchange has taken place; that is, he must determine "who won." He will think in terms of the assets that survive the war—i.e., some set of "value elements" or "value structure" that will be important in reconstructing the two societies. In any real projection of the world we live in, this will lead him to divide his weapons to serve two purposes. First, he will use some (N_1) to reduce the magnitude of the retaliation. Second, he cannot neglect to use others (N_2) to attack the value structure of the enemy. He cannot, for example, put all his weapons in the N_1 basket for fear that his cities and towns (or whatever he most values in his national infrastructure) will be devastated while those of his enemy would be untouched. Nor can N_1 be zero if his opponent's forces are at all vulnerable, because each enemy weapon destroyed is a value element saved on his own side.

This, then, is the quandary faced by the strategist contemplating a first strike. First of all,

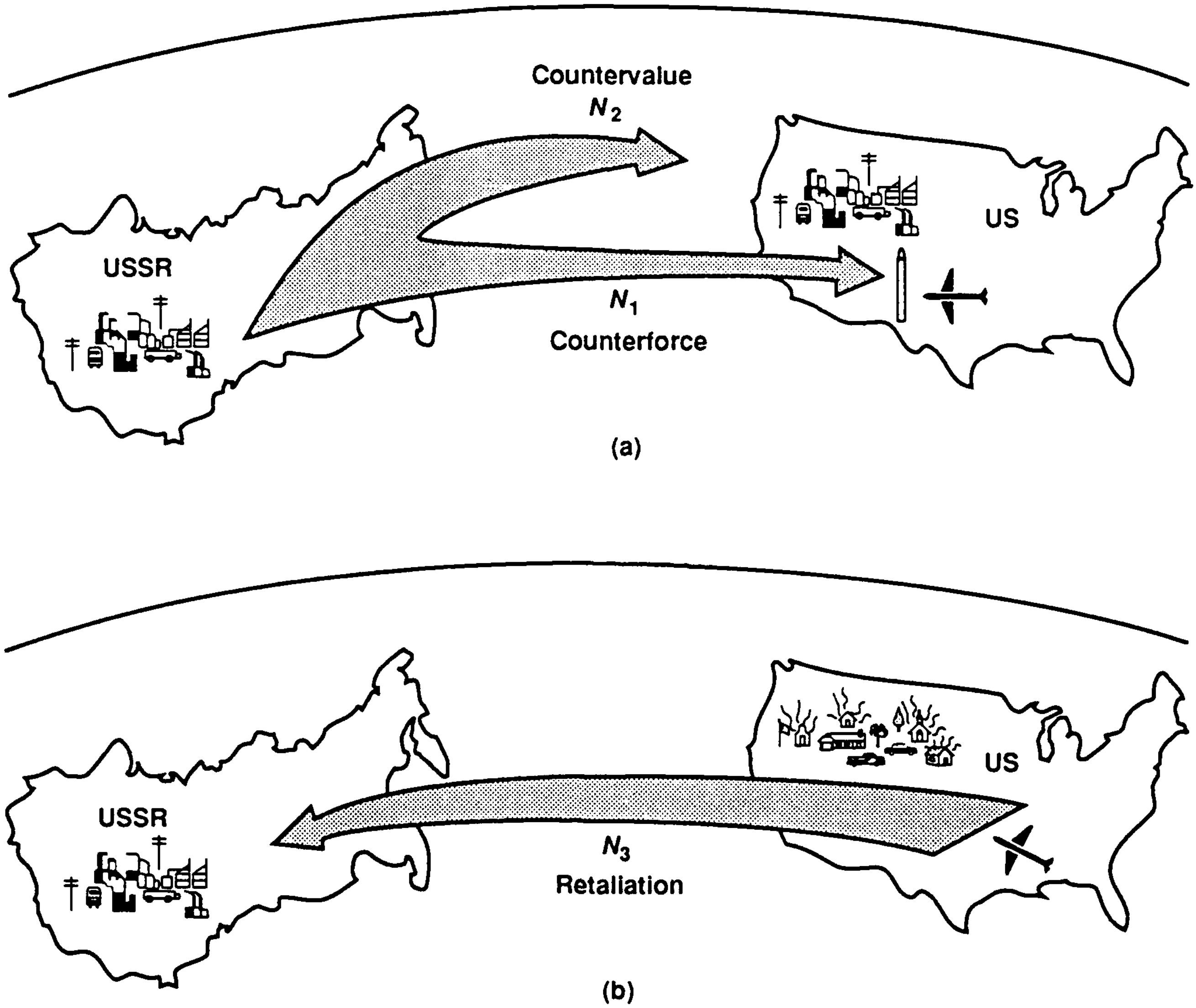

Figure 1. In a nuclear exchange, the first strike (a) may consist of a counterforce attack against the adversary's strategic weapons (N_1) and a countervalue attack against the adversary's value structure (N_2). In (b), the adversary's retaliation (N_3) would complete the exchange.

should he strike or not? Will he be "better off" if he does so? How does he measure "better off"? In the final analysis, if he does decide to strike, what is his optimal strategy? This last is far more complex than merely deciding the size of N_1 and N_2. He must consider the precise allocation of each of his own weapons in attacking those of the enemy, as well as the weight of his countervalue strike in terms of all possible sets of attacks on the enemy. Stated in more quantitative terms, the task is to determine a strategy that minimizes N_3 (the size of the retaliatory strike), subject to certain constraints that may arise from whatever he determines to be his "better off" criteria.

Damage and Deterrence

Figure 2 shows two generalized "integral curves" showing damage done to a societal value structure by increasing the numbers of nuclear weapons. Fundamental to analytical thinking as

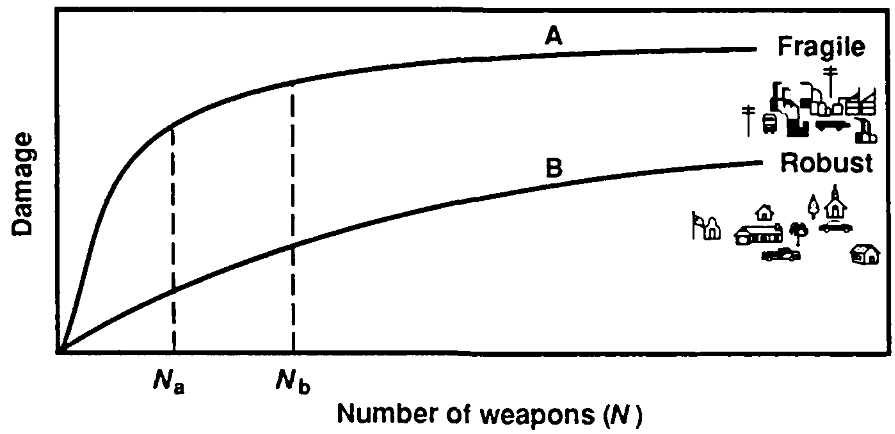

Figure 2. Integral damage curves. For a fragile society, the damage inflicted (curve A) would rise rapidly with the number of weapons employed, whereas a robust society would be able to absorb much more punishment without experiencing a similar level of damage (curve B). "Damage," in this case, is defined as the destruction of the means of a society to function. A society consisting of highly urban concentrations of interdependent people and infrastructure would be "fragile," whereas a largely suburban society consisting of semiautonomous entities would be "robust." If the number of weapons used is reduced from N_b to N_a, the corresponding reduction in the level of damage inflicted would be considerably different for the two societies.

any such curve may be, a few of its underlying assumptions should be kept in mind. The term "damage," like the term "cost," needs to be assigned some measure if we are to speak in quantitative terms. In drawing a curve such as those in Fig. 2, we *define* the "value" of targets in a given society, and equate "damage" with "value destroyed" in the same sense that the cost of an item is defined in dollars. Each curve is based on assumptions of an ordering of weapons and of value. The value structure is broken down into aimpoints, which are assumed to be destroyed by the weapons assigned thereto. Weapons, in order of effectiveness, are assumed to be assigned in incremental fashion against prioritized targets. In this process, the value of each aimpoint is quite arbitrary and is determined by the analyst who draws the curve. To finesse this problem, Fig. 2 specifies no numbers, either of weapons or targets. Rather, it is merely a cartoon that implies that the ordering and assignment of targets has been done in a consistent way; i.e., the targets have been ranked in value and attacked in value order. (One-million dollar targets are not attacked until all two-million dollar targets have been covered, for example.)

This pedantic explanation is important because much of the disagreement found in strategic arguments hinges on the arbitrary nature of the values different people believe to be implicit in the target society, which is an essential parameter in drawing an integral damage curve. Comparing a steep curve, A, with a gradual curve, B, illustrates the difference between those strategists who think that total damage rises quickly to approach some large limiting value—a very valuable and fragile society—and those who think that it rises quite slowly and perhaps approaches a lower limit for a society deemed more robust, (i.e., less easy to injure). It is important to recognize that the arbitrary nature of judgment as to what constitutes "value" means that both curves A and B could be intended to represent the same society as evaluated by two strategists with different schools of thought.

Two more points are important. In Fig. 2, the upper limit for curve A has not been given a value, although it has been typical of our thinking that destruction approaches 100%. Note that the school of thought used to plot curve B appears to include the assumption that essentially half of the robust target society's value is not vulnerable even when large numbers of weapons are used. One can easily understand that large disagreements evolve between the two schools as to how many weapons actually constitute a deterrent for the target society involved. Also, in the construction of a two-power agreement to limit or reduce strategic arms, such considerations must be taken into account despite the fact that they cannot be rigorously quantified. If the number of weapons delivered changes from N_b to N_a, the change in the damage expected by the two schools can be quite different.

Before we leave Fig. 2, we do have some empirical evidence that bounds it. We know that, today, N is of the order of several thousand, at least for the nation making the first strike. This makes it reasonable to believe that analysts are accustomed to thinking in terms of hundreds or thousands of targets. Indeed, turning to any modern atlas or census, we find the number of urban targets with significant population and wealth to be in the thousands (see Table 1).

With this evidence, even given the alleged propensity of the Soviets to build far more military items than they think they need, it appears that they may have constructed their stockpile to cover thousands, rather than tens, of aimpoints. The same might be said for the US, since the Soviet societal structure is now rather like our own in terms of urbanization.

For almost a quarter of a century, we have grown accustomed to nuclear arsenals that could blanket both the US and the USSR down to very small target elements, certainly in a first strike and probably (see Counterforce Incentives) in a retaliatory strike. Even the rationale for the much-advertised buildup of US strategic forces beginning in the last decade did not depend so much on the danger posed by the dwindling deterrent as it did on the concept of strategic equivalence and perhaps later, the peace-through-strength argument that the Soviets would continue to augment their own nuclear strength until assured that the US would keep pace, at which time an environment more favorable to arms control might exist. The fact is that, for 25 years, almost all strategic thinkers in the US have believed that our deterrent was adequate. Some thought it was greater than needed, while others worried about its erosion as Soviet counterforce capabilities increased, but few were inclined to panic. Now, on the eve of deep reductions, it is prudent to review our understanding of deterrence and damage limitation.

Counterforce Incentives

Referring again to Fig. 2, we see that the reduction of N by a factor of 2 (from N_b to N_a) may or may not, according to the analyst's construction of his damage curve, lead to a concurrent reduction in damage of roughly the same amount. *Further quantitative evaluation of the* subject leads us to think in terms of the amount of damage reduction on an incremental basis.

Figure 3 conceptualizes a typical differential damage curve. (It is not the differential of either of the specific curves in Fig. 2.) It answers the question as to how much damage is done by the Nth weapon, given that no changes in the assumed value structure are made during the attack and that weapons are assigned to targets

Table 1. US demography in 1980.

Population of urban target	Number of targets	Population (millions)	% urban	% of total population
Larger than 1 million	6	17.5	11.4	7.7
500,000 to 1 million	16	10.8	7.1	4.8
250,000 to 500,000	34	12.2	8.0	5.4
100,000 to 250,000	117	17.0	11.1	7.5
50,000 to 100,000	290	19.8	12.9	8.7
25,000 to 50,000	675	23.4	15.3	10.3
10,000 to 25,000	1765	27.6	18.0	12.2
5000 to 10,000	2181	15.4	10.1	6.8
2500 to 5000	2665	9.4	6.2	4.1
Total	7749	153[a]		

[a] Total population: 227 million, urban population: 167 million. The urban population contained in these 7749 listed places totals to 153 million.[8]

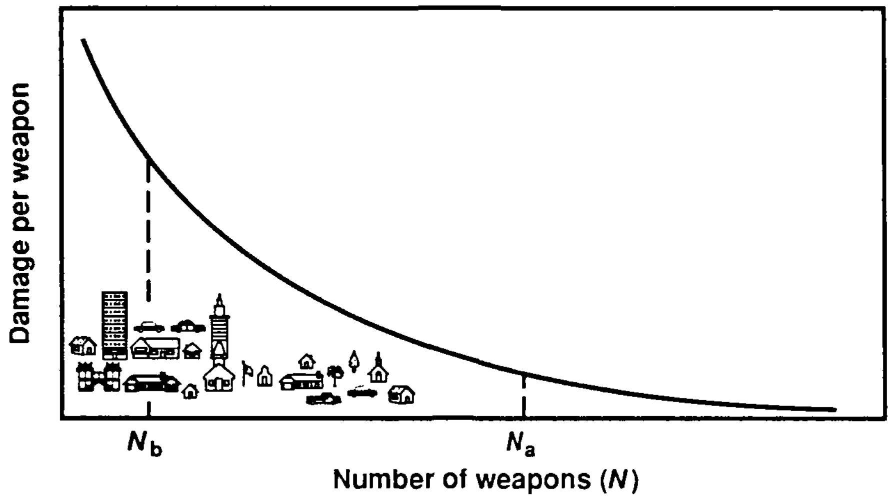

Figure 3. Differential damage curve. The damage inflicted by the first few nuclear weapons (N_b) to a target society is quite high in comparison to the additional damage inflicted as the number of weapons employed increases (N_a).

in order of priority. The shape of Fig. 3 is similar to that derived from simulations made with the value structure used for the US in Section III.

Probably the most striking aspect of this, or any other, realistic differential damage curve is the increasing steepness of the curve as N decreases. The first few weapons cause by far the most damage on a per-weapon basis. It is fairly easy to make the case that the US and the USSR contain value-target tiers r 't unlike those represented for the base case of this analysis. This is not the same as the total value that exists in the two societies. Some would agree that several thousand aimpoints contain almost all the wealth in the US, while others would maintain that cities and towns represent only the manifestation of a nation's wealth—certainly not the basic source of it. All would probably agree that, at some point along the differential curve, it would be worth expending considerable effort to save targets from enemy weapons.

Limiting Damage

Let us now consider two methods of saving targets, or limiting damage: first, active defense by means of antiballistic missiles and air defense (interceptor aircraft together with surface-to-air missiles) and second, counterforce attacks intended to destroy the strategic offensive forces of the enemy. Passive defense—the dispersion, hardening, and hiding of assets in conjunction with steps taken to speed recovery and ameliorate post-war effects—is not taken as lightly in the USSR as it is in the US and represents an important potential for limiting damage, particularly if used in conjunction with active defense and counterforce attacks. For this discussion, we assume that the effectiveness of passive defense measures, where they exist, has been taken into account in constructing the schedule of assets represented by the differential and integral damage curves, and we hereafter say no more about them.

Active defense, usually considered under the rubric of SDI or "Star Wars," is a means of defending both cities and strategic nuclear assets in order to dilute an attack or force the attacker to move to a less-damaging distribution of his weapons. As an extension of previous work,[1] we made a number of simulations of active defense in a START environment (see Strategic Defense by the US on pages 18 and 19).

The utility of counterforce attacks intended to limit damage is not always so obvious. At this point, we must stress the link between damage limitation and vulnerability. Without vulnerability in opposing strategic forces, counterforce strikes are meaningless. Clearly, if no systems are vulnerable, it is a waste of weapons to attack them. If one side has vulnerabilities in its strategic nuclear forces, an opponent may be able to take advantage of these by a first strike. In such cases, the incentive to make a first strike works to the detriment of crisis stability.

To see this graphically, we refer again to Fig. 3 at the point where a vertical line from N_a intersects the differential curve. Even a large decrease in the number of delivered weapons from this point does not greatly change the destruction to be expected from each weapon. In a word, both sides are indifferent as to whether N_a weapons or $(N_a - 1)$ or even $(N_a - \text{many})$ are delivered. Now we go to N_b, at a vastly decreased number of weapons; here the damage per weapon is large and changes rapidly with N. Thus, there is a significant difference between the damage done by N_b and by $(N_b - 1)$ weapons. Also important is the fact that this difference increases rapidly and inversely with number of weapons: elimination of weapon $(N_b - 1)$ is more important in limiting damage than is elimination of weapon N_b. As N approaches zero, the value destroyed by each weapon, or saved by the elimination of that weapon, becomes large indeed.

To put it in a slightly different way, assume that one side (Red) has 100 targets of value and the other side (Blue) has 200 deliverable warheads with which to attack Red. Red is not much interested in the destruction of 50 of those Blue warheads; that would do nothing to limit damage to his 100 targets. However, if Red could destroy more than 100 Blue warheads, he would be tempted to do so even if this meant he would have to initiate hostilities. Of course, the more weapons Red believed he could destroy, the more incentive he would have to do so.

This incentive to limiting damage can be intensely destabilizing. The higher the likelihood of decreasing the number of Blue's retaliating weapons, the more incentive there is for Red to do so in a first strike. Given a sufficient vulnerability on Blue's side, Red would find it profitable to use even marginally effective forces in a counterforce strike of alarmingly robust proportions.

Kill Probabilities and Multiple Attacks

In view of the foregoing discussion, it appears that it may pay dividends to use more than one weapon to disable a single enemy warhead. Table 2 displays the mathematics of survival in this regard. For a reasonable range of kill probabilities, we see the expected numbers of survivors among 1000 ICBMs, assumed to carry one warhead each. Note that, for single-warhead attacks, even a high kill probability leaves a formidable deterrent: 200 survivors for $P_k = 0.8$. However, a 2-on-1 or 3-on-1 attack, although expensive in terms of warhead expenditures, reduces the number of survivors to the extent that an acceptable damage potential may exist in the eyes of an adversary.

Thus, it is clear that vulnerability is a matter of degree: most would agree that 600 survivors expected after a 1-on-1 attack for $P_k = 0.4$ is "a lot" but that the much lower numbers for 3-on-1 attacks at higher probabilities fall short of a sufficient retaliatory deterrent.

This concern over multiple attacks is the root of the US objection to the 308 heavy SS-18 ICBMs deployed by the Soviets. The limitations proposed in START, as well as they are known at this writing, do nothing to ameliorate the foregoing analysis. To be sure, START will reduce the number of Soviet reentry vehicles available for multiple-weapon attacks, but it will also reduce the number of target SNDVs deployed in the US strategic forces of the 1990s. We discuss specific examples of this in the next section.

It would be wrong to leave this short discussion of the expectation value for survivability on too pessimistic a note. Two related points need to be made. The first is that the value of the kill probability for any system will remain a perception or estimate until after an exchange has taken place. Referring back to Table 2, we can see the consequences an analyst would face if he thought his kill probability was 0.7, but it turned out to be 0.5 instead. Such uncertainty probably enhances prevenient stability because of the caution it engenders. A second point raised by the same numerology is that a small decrease in vulnerability can go a long way, as can be seen from the tables.

Table 2. Survivors expected for various attacks and selected single-shot kill probabilities (P_k) on 1000 ICBMs.

	Number of survivors expected for attacks with		
P_k	1 weapon per target	2 weapons per target	3 weapons per target
0.4	600	360	216
0.5	500	250	125
0.6	400	160	64
0.7	300	90	27
0.8	200	40	8

Consider a simple example. Given $P_k = 0.8$, 1000 warheads aimed at 1000 fixed ICBMs would leave only 200 survivors. However, if the target ICBM could be shuttled back and forth between two aimpoints with no prior knowledge on the part of the attacker as to which of the two aimpoints was the true location, then the same 1000 attacking warheads would leave 600 survivors. In this case, mobility would have the same effect as cutting the kill probability in half.

III. Simulations and their Results

EXCHANGE 8.7*

In Section II, we used Fig. 1 and the associated text to outline the problem to be solved by a strategist evaluating the outcome of a first strike and anticipating a follow-on retaliatory strike. The code EXCHANGE 8.7 was formulated to give us insight into this problem, and we use it to make four comparisons (see Tables 3–6). To start out, we list the assets of the two sides, including both societal value structure and strategic nuclear capabilities, much as has been done in Tables 1 and 5. This list is transformed into input data for the code by including force-alert rates as well as force-on-force and force-on-value interaction arrays (similar to kill probabilities), as has been done in Table 6, for example. We define a value function, V, and the "rules" governing the nuclear exchange: the first-strike side will formulate optimal strategies to maximize V, and the retaliatory side will do its best to minimize V. Thus, V will at once be the largest value that the first-strike side can hope to attain and the smallest value the retaliatory side can hope for. This "minmax value" V is the result of the exchange when optimal strategies are used on both sides. EXCHANGE 8.7 does this calculation for a value function that is defined as the difference between the residual assets of the two sides after the exchange. That is, V equals the remaining assets of the first-strike side minus the remaining assets of the retaliating side. This value can be either negative or positive.

In discussing first-strike incentives, it is important to realize that *either* side has the option of making a first strike, national disclaimers of any intent to do so notwithstanding. Thus, for any given scenario (e.g., the one represented in Table 6), either the US or the USSR can make the first strike. To simplify discussion, we use V to refer to a Soviet first strike, and V' to refer to a US first strike.

* This and the following section dealing with prevenient stability are intended to describe, for the reader not familiar with our previous work, the basic analytic methods used here (see also Refs. 1, 2, and 5).

Prevenient Stability

By the term "prevenient stability," we refer to the disincentive to make a first, or prevenient, strike. (We use the word "prevenient" to stress the anticipatory nature of such an attack; we do not use "preemptive" because we do not wish to convey a meaning of interference with an opponent's plans for attack.) Prevenient stability declines when either of two potential antagonists finds a *direct* benefit in striking first or finds a *strategic* benefit in striking first rather than suffering a *first strike*. Prevenient stability is strong when there is no benefit to making a first strike or when the benefit is so small compared to the cost that any first strike is deterred; it increases as the advantage to be gained by a first strike is reduced. Prevenient stability has two measures: crisis stability and deterrence.

Crisis stability involves a comparison that reverses the roles of attacking and retaliating sides. We compare the results of two exchanges: first, a Soviet first strike on the US followed by a US retaliation (V), and second, a US first strike on the Soviets followed by Soviet retaliation (V'). The sum, $V + V'$, represents the cost of not being first to strike and, as such, gives us some information about the degree of crisis instability inherent in a given situation. The question "Is it to my advantage to strike first rather than to suffer a strike by the other side?" is measured by the quantity $V + V'$ for *both* sides.

An equally important measure of prevenient stability is deterrence, a term that connotes the reluctance to make a first strike because of the terrible damage to be expected in the return strike. Deterrence may balance crisis stability. Even if it is better to strike first than to let one's

Table 3. Sets of simulated exchanges described.

Ia. 1990 Scenarios

1. 1990 base case. "Most likely" force structures. Table 4 gives the exact input data used in the exchange.
2. Like 1, with no strategic force vulnerabilities on either side (all SNDVs invulnerable.).
3. Like 1, assuming the SSBNs on both sides are invulnerable. (ICBMs and strategic air are vulnerable.)
4. Like 1, assuming only ICBM forces are not vulnerable.
5. Like 1, assuming only strategic air forces are not vulnerable.

Ib. START Scenarios

6. START base case. "Best-estimate force structures." Table 6 gives exact input data used. The "worst case" examined for this scenario. Note: value structure is the same as in exchange 1.
7. Like 2, for this scenario. No force-on-force vulnerabilities.
8. Like base case, but SSBN are invulnerable.
9. Like base case, but ICBM are invulnerable.
10. Like base case, but strategic air forces are invulnerable.
11. Like 6, with 100 MX ICBMs substituted for 1000 Midgetman ICBMs. MXs are in fixed sites. A "worst-case" excursion.
12. Like 6, except we assume Soviets have taken advantage of START bomber counting rules to add 1000 weapons to their alert strategic air forces.
13. Like 6, with the number of value targets doubled (twice as many as in Table 6).
14. Similar to 13. The number of value targets is the same as the base case, but the value of each is twice as large.

II. VIT Scenarios

15. START base case repeated for convenience of comparison. Exchange 15 is identical to 6 in all respects.
16. Identical to 7, repeated for convenience. No force-on-force vulnerabilities.
17. Like 16, except that US ICBMs are removed from input, to simulate failure by VIT.
18. Like 16, except the VIT failure is in the strategic air force.
19. As above, but simulation applies to removal of US SSBN force by VIT.
20. Like 15, the START base case, but the US ICBM force is removed by VIT (*the vulnerabilities of Table 6 still apply*).
21. Similar to 20, but VIT removes the US strategic air force rather than the ICBM forces.
22. Similar to 20, but US SSBN force is removed by VIT. A "worst-case" excursion.

III. Strategic Defense of US Assets

23. Base case for START repeated for convenience. 23 is identical to 6 and 15.
24. Like base case, but assuming a perfect defense of US ICBM.
25. Like 24, but in this case we assume a perfect defense of alert US strategic air forces.
26. Perfect defense of both US ICBMs and alert strategic air forces.

Runs 27 through 31 examine defense of US value structure.

27. 20% effective defense.
28. 40% effective defense.
29. 60% effective defense.
30. 80% effective defense.
31. 100% effective defense—US value structure "invulnerable."
32. Simulates 100% effectiveness in the defense of value assets against Soviet ICBM and SLBM forces, but no air defense against Soviet strategic air forces.

IV. Scenario "Beyond START"

33. Beyond START base case. Assumes a further 50% reduction after START. The number of SNDVs shown in Table 6 is reduced by half. Kill-probability arrays are not changed; neither is value structure.
34. Like 33, but all forces are invulnerable.
35. Like 33, but US SSBN force is disabled (removed) by VIT. A "worst-case" excursion.
36. Like 33, but a 50% effective defense of US value targets is assumed.
37. Like 33, but a 100% effective defense is assumed.

Table 4a. Input data for the 1990 base case.

Index	Number	Aimpoints	Warheads/value per target
USSR			
1	308	308	10
2	360	360	6
3	100	1000	10
4	25	25	80
5	20	20	50
6	25	25	100
7	500	500	30
8	3500	3500	3
US			
1	50	50	10
2	500	500	3
3	450	450	1
4	24	24	170
5	12	12	200
6	50	50	100
7	400	400	30
8	3000	3000	3

Table 4b. P_k: Column I shoots at row J.

US force index	USSR force index					
	1	2	3	4	5	6
1	0.700	0.600	0.600	—	—	—
2	0.700	0.600	0.600	—	—	—
3	0.800	0.700	0.700	—	—	—
4	—	—	—	—	0.020	—
5	—	—	—	0.300	—	—
6	0.600	0.500	0.600	0.400	0.610	—
7	0.700	0.600	0.700	0.600	0.710	—
8	0.800	0.800	0.800	0.800	0.900	—

USSR force index	US force index					
	1	2	3	4	5	6
1	0.700	0.300	0.100	—	—	—
2	0.800	0.300	0.100	—	—	—
3	0.800	0.600	0.500	—	—	—
4	—	—	—	—	0.020	—
5	—	—	—	0.400	—	—
6	0.600	0.400	0.600	0.400	0.610	—
7	0.700	0.600	0.700	0.500	0.710	—
8	0.800	0.800	0.800	0.800	0.900	—

Table 5a. Strategic forces of the US, 1990 (from Ref. 9).

Type	Number	No. warheads	Remarks
ICBM			
Peacekeeper (MX)	50	≤10	Newest US ICBM.
Minuteman II	400	1	Deployed in 1960s.
Minuteman III	550	3	Some hard-target capability.
SSBN			
Lafayette/ Ben Franklin	28	16 SLBM	Armed with C-3 & C-4 SLBM.
Ohio (Trident)	10	24 SLBM	Carries C-4 SLBM. Will carry Trident II.
SLBM			
Poseidon (C-3 & C-4)	448	8 to 10	
Trident (C-4)	240	8	To be replaced by Trident II.
Bombers			
B-52G/H	250	≥8	Most are modernized to carry cruise missiles.
B-1B	100	≥8	Deployed in mid-to-late 1980s.

Table 5b. Strategic forces of the USSR, 1990 (from Ref. 9).

Type	Number	No. warheads	Remarks
ICBM			
SS-18	308	≤10	Most powerful ICBM.
SS-17, 19	510	6	Same size as US MX .
SS-11, etc.	320	1–4	Older types; SS-11 phasing out.
SS-24	100	10	Large, rail mobile.
SS-25	200	1	New, road mobile.
SSBN			
Yankee	15	12–16 SLBMs	Oldest class, being replaced.
Delta I–IV	41	16 SLBMs	D-III & IV are modern SSBNs.
Typhoon	6	20 SLBMs	Newest-class SSBN in USSR.
SLBM			
SSN 20	120	6 to 9	On Typhoon only.
SSN 23	80	10	On Delta IV SSBN; newest SLBM.
SSN 18	224	≤7	On Delta III SSBN.
SSN 6, 8, 17	500	1 or 2	Older missiles on older SSBNs.
BOMBERS			
Backfire	290	A few	One-way range is 8000 km.
Bear	160	A few	New models carry cruise missiles.
Blackjack	15	≤10	Soviet equivalent to B-1B.

Table 6a. Input data for the START base case.

Index	Number	Aimpoints	Warheads/value per target
USSR			
1	100	1000	10
2	100	100	10
3	20	20	100
4	20	20	50
5	25	25	100
6	500	500	30
7	3500	3500	3
US			
1	1000	1000	1
2	14	14	183
3	12	12	68
4	50	50	100
5	400	400	30
6	3000	3000	3

Table 6b. P_k: Column I shoots at row J.

US force	USSR force index					
index	1	2	3	4	5	6
1	0.800	0.800	0.700	—	—	—
2	—	—	—	0.020	—	—
3	—	—	0.400	—	—	—
4	0.600	0.600	0.400	0.610	—	—
5	0.700	0.700	0.600	0.710	—	—
6	0.800	0.800	0.800	0.900	—	—

USSR force	US force index					
index	1	2	3	4	5	6
1	0.800	0.700	—	—	—	—
2	0.800	0.700	—	—	—	—
3	—	—	0.020	—	—	—
4	—	0.400	—	—	—	—
5	0.400	0.400	0.610	—	—	—
6	0.600	0.500	0.710	—	—	—
7	0.800	0.800	0.900	—	—	—

enemy do so, the incentive to strike is held in check by the fear of retaliation. To make a comparative quantification of deterrence, we use a scale from 0 to 1, defined so that the damage is a maximum at 0 and a minimum at 1. We define the term "residual value fraction" (RVF) as the fraction of a nation's value structure that survives a war; that is, the total point value of the value elements surviving the exchange, divided by the pre-war point value of those same assets.

The Four Comparisons

Tables 3 through 6 provide the key to a relatively painless perusal of the data acquired in the exchanges simulated. Since details of force structure are highly important in any study of this nature, we have used a number of input-data variations in this paper to see what useful generalizations can be made over a range of scenarios. The input data for each simulation are given in Table 3. Table 4, often referred to as the base case for the status quo, shows the forces on the two sides and the kill-probability arrays approximately as they exist in 1990. Table 5 reviews the strategic systems of the US and the USSR for those readers who are not familiar with the strategic balance today. Table 6 is the input data for the base case for the START-constrained scenario, circa 1998.

Table 7, a condensed and comprehensive representation of the results of our analysis, needs a few words of explanation. The first column is simply a number by which we can refer to the particular exchange scenario simulated. The second is a memory aid—a condensation of the scenarios described in Table 3, so that the reader need not turn back to that table so often. Columns 3 and 4, V (USSR) and V' (US) list the minmax value functions calculated by EXCHANGE. As previously, the algebraic sum $V + V'$ is a measure of crisis stability. The next four columns are RVF_1 (US and USSR) and RVF_2 (US and USSR). The terminology here bears watching: subscript 1 refers to the RVF for the nation assumed to make the first strike, while subscript 2 pertains to the retaliating side. For example, in the first exchange (base case, Table 4), if the US makes the first strike, 26% of its value structure survives ($RVF_1 = 0.26$) and only 10% of the Soviet value structure survives ($RVF_2 = 0.10$). *If the USSR makes the first strike,* 43% of Soviet assets survive (RVF_1) compared to only 8% for the US (RVF_2). The last column, N_1, gives the total number of Soviet warheads used in the counterforce role for a Soviet first strike (the same N_1 as in Fig. 1) and is useful as a measure of the intensity of the Soviet damage-limiting strike.

The data presented in this section are arranged to facilitate the four basic comparisons, which we mentioned in the Introduction as being important to consider; namely,

- START with the 1990 strategic situation.
- Vulnerability induced by technology (VIT) under START.
- START with and without SDI.
- Arms reduction beyond START.

These comparisons are summarized in Table 7 and are discussed in the remainder of this section.

START and the 1990 Strategic Balance

Here, in a sense, we are comparing apples and oranges. That is to say, we are comparing 1990 forces as they actually exist with our best estimate of START-constrained forces, circa 1998. The scenarios in section Ia of Table 7, which are based on Table 4, have more than twice as many weapons as are used in section Ib, which is based on Table 6. The value structure for all simulations is the same; START will not change them.

Since vulnerability is such a key issue, we first consider the extreme differences that exist for various assumptions in that regard. When no force-on-force vulnerabilities exist, $V + V' = 0$ (exchanges 2 and 7). In this case, all weapons are used to attack value structure, so it makes no difference who strikes first. These results are to be expected from the discussion of Section I, because we have "assumed out" any possibility of limiting damage. Even under this assumption, the reader should note that if an exchange does occur, very little remains of the value structure on either side (RVFs are small). Many observers would assess the no-force-on-force vulnerability situation as satisfactory, crisis instability as acceptable, and deterrence as high (RVFs smaller than 10% would not seem to make a first strike desirable). Even if only one leg of the US Triad [bombers, land-based ICBMs, and submarine-launched ballistic missiles (SLBMs)] is completely survivable, prevenient stability is relatively strong (scenarios 3–5 and 8–10). However, when the more realistic vulnerabilities of Tables 4 and 6 are taken into account, this is no longer true.

In discussing Fig. 3, we pointed out that, for small numbers of weapons, the incremental damage per weapon could be so large that emphasis might be placed on limiting damage. This is precisely the effect we see throughout Table 7 when vulnerabilities exist (e.g., scenarios 1, 6, 11, and 12). In some cases, even the US second-strike RVF increases for a Soviet first strike because the optimal Soviet attack strategy dictates the removal of first-strike warheads from US value targets in order to assign them to US SNDVs. This increases the rate of survival of Soviet high-value targets to a greater extent than for the US and, hence, proves to be the optimal strategy.

In comparing START with the status quo, we see that first-strike RVFs are generally larger for the constrained case. Part of this increase is a result of the fact that fewer weapons are available under START, and, since the value structure is unchanged, fewer weapons can be expected to do less damage. The START simulations invariably use all the weapons on both sides, while today one would expect many weapons to remain on one or the other side, depending on the degree of

Table 7. Results of the exchanges simulated.

Exchange No.	Remarks	V USSR	V' US	RVF_1 US	RVF_1 USSR	RVF_2 US	RVF_2 USSR	N_1
	Ia. 1990 Simulations							
1	1990 base case (Table 4)	10,718	4,134	0.26	0.43	0.08	0.10	3,840
2	No force vulnerabilities	1,105	−1,105	0.07	0.07	0.07	0.07	0
3	Base with no SSBN vulnerability	6,875	2,859	0.15	0.21	0.07	0.08	1,842
4	Base with no ICBM vulnerability	5,939	−45	0.08	0.13	0.08	0.07	1,240
5	Base with no strat. air vulnerability	2,912	972	0.08	0.14	0.08	0.08	3,600
	Ib. START Simulations							
6	START base case (Table 6)	10,419	337	0.33	0.58	0.22	0.29	2,132
7	No force vulnerabilities	2,905	−2,905	0.07	0.15	0.07	0.15	0
8	No SSBN vulnerability	6,656	265	0.25	0.33	0.10	0.23	1,000
9	No ICBM vulnerability	8,658	−1,613	0.11	0.42	0.11	0.16	1,000
10	No strategic air vulnerability	5,876	−2,078	0.10	0.32	0.11	0.17	1,000
11	Like 6, but 100 MX	14,115	337	0.33	0.65	0.16	0.29	1,432
12	Like 6, but 2000 USSR air weapons	14,995	278	0.33	0.79	0.27	0.30	3,694
13	Like 6, but 2 × No. targets	22,696	−2,492	0.40	0.78	0.40	0.42	3,100
14	Like 6, but 2 × value targets	20,838	674	0.33	0.58	0.22	0.29	2,132
	II. VIT Scenarios							
15	START base case, like 6	10,419	337	0.33	0.58	0.22	0.29	2,132
16	No force vulnerabilities	2,905	−2,905	0.07	0.15	0.07	0.15	0
17	Like 16, but US ICBM out	5,498	−5,498	0.07	0.24	0.07	0.24	0
18	Like 16, but US strategic air out	5,605	−5,605	0.07	0.25	0.07	0.25	0
19	Like 16, but US SSBN out	8,615	−8,615	0.07	0.25	0.07	0.25	0
20	Like 15 (base), but US ICBM out	14,915	−2,747	0.28	0.65	0.13	0.36	1,132
21	Like 15, but US strategic air out	10,767	355	0.29	0.58	0.21	0.38	2,000
22	Like 15, but US SSBN out	20,869	−8,183	0.10	0.95	0.22	0.39	2,156
	III. Strategic Defense of US Assets							
23	START base case (like 6)	10,419	337	0.33	0.58	0.22	0.29	2,132
24	US ICBM defended	8,658	337	0.33	0.42	0.11	0.29	1,000
25	US strategic air defended	5,900	337	0.33	0.32	0.11	0.29	1,000
26	Both air & ICBM defended	5,800	337	0.33	0.31	0.11	0.29	950
27	20% effective city defense	7,928	3,278	0.32	0.62	0.36	0.18	3,144
28	40% effective city defense	6,578	4,218	0.36	0.59	0.46	0.18	2,638
29	60% effective city defense	4,547	5,498	0.50	0.59	0.46	0.27	2,450
30	80% effective city defense	390	10,307	0.59	0.58	0.61	0.18	2,144
31	100% effective city defense	−6,304	18,012	1.00	0.64	1.00	0.17	3,144
32	Like 31, but no air defense	2,502	17,626	0.99	0.55	0.49	0.30	2,594
	IV. Beyond START							
33	One-half Table 6 forces	11,348	−1,246	0.40	0.78	0.40	0.42	1,550
34	Like 33, no force vulnerability	3,616	−3,616	0.25	0.36	0.25	0.36	0
35	US SSBN removed by VIT	17,547	−6,185	0.29	0.97	0.37	0.49	1,078
36	50% effective city defense	6,936	4,683	0.71	0.74	0.53	0.49	1,066
37	100% effective city defense	−2,842	14,003	1.00	0.83	1.00	0.43	1,578

vulnerability and the size of the counterforce strike. Simulations 1–5, for example, indicate that today we could expect several thousand Soviet and US weapons to remain after most exchanges. For the same scenarios with START forces, simulations 6–14 show that both sides use all their weapons in an optimal exchange.

Another reason for the change in RVFs is accounted for by the damage-limiting tactics used in the first strike when vulnerabilities exist. Without START, even when critical vulnerabilities are assumed, usually enough weapons survive on the retaliating side to cover at least the high-value targets of the attacker. This is not always the case under START. One would tend to argue that destruction of a large fraction of the Soviet value base under the 1990 scenario constitutes a good deterrent. The fact that the comparable number under START is only about half as large should not be taken as proof that the deterrent has vanished, particularly in view of our caveat that numbers mean little here in the absolute sense. However, the trend is meaningful, in that the scenarios are precisely comparable. Deterrence is not necessarily enhanced by START; in fact, the simulations of Table 7 indicate just the opposite.

Scenario 11 addresses the possibility that 100 silo-based MX ICBMs could be the system of choice for the US. If so, a Soviet first strike would attack each MX silo with three SS-18 reentry vehicles, and the Soviets would benefit from the concentration of warheads in so few aimpoints. Although the simulation is not included in Table 7, if the US used an effective mobile system for basing MX, the Soviet gain would be smaller. In fact, a system providing ten aimpoints per mobile MX ICBM would be identical to the base case.

START "counting rules" allow a bomber that is not a cruise missile carrier to be tallied as only one warhead and one SNDV. However, modern strategic intercontinental aircraft can carry many short-range attack missiles and gravity bombs. Either side could deploy more weapons than are used as input to the START base case (Table 6) simply by loading up bombers with weapons other than cruise missiles. Scenario 12 simulates an additional 1000 air-delivered weapons on the Soviet side and indicates the destabilizing effect this "loophole" in START could have. Compared to the base case, we see V rise to almost 15,000 from 10,419, and RFV_1 (USSR) increase from 0.58 to 0.79. If START counting rules remain unchanged, the US would do well to look toward improved air defenses.

The last two simulations of this section investigate the effects of doubling the value structure by both sides. In one case (13), this is done by doubling the number of targets; in the other, by doubling the value of each target. Changing the value of each target represents a change of scale only, much as if, in a rubber of bridge, the stakes were twice as large. In this case, optimal play of the hands would not change, and so it is in scenario 14. The only change from base-case results is that V and V' are twice as large.

If the number of targets is doubled, the importance of limiting damage is emphasized. Consequently, both sides concentrate more of their forces in the counterforce phase of a first strike. As we saw in the discussion of Fig. 3, more-valuable societies are damaged more heavily by nuclear attack and therefore have greater incentive to limit damage. Generally, strategic-force vulnerability and great societal wealth go hand in hand to tempt a prevenient attack.

In sum, this first set of simulations indicates that there does not seem to be a great deal of difference between the constrained and the unconstrained scenarios as long as strategic forces are relatively invulnerable. However, in those scenarios in which vulnerability is assumed, particularly in the SSBN force, crisis stability is fragile and deterrence is reduced. Since the US does rely heavily on its SSBN force, it is not surprising to find that, if vulnerabilities are assumed here, prevenient stability suffers. What may be less obvious to most observers is that START does not help matters. Indeed, in the simulations made here, START exacerbates the erosion of deterrence.

Vulnerability Induced by Technology (VIT)

The next set of simulations examines the consequences if vulnerabilities induced by the burgeoning technology expected in the next decade lead to a disabling of any one branch of the US Triad.

A look at Table 7, exchanges 15–19, makes it clear that VIT of any given branch of the Triad under START would not in and of itself provide an unmanageable change in prevenient stability. Unfortunately, the assumption that leads to this statement is that there are no force-on-force vulnerabilities of the type shown in Table 6. Thus, the world of START has two faces. If we can control vulnerability by international agreement or by active/passive countermeasures, we can look forward to a worst-case possibility (19) that most would find tolerable. (The loss of the undersea branch of the US Triad in its entirety surely comprises a strong "worst case.") It is clear that if no vulnerabilities exist other than those caused by VIT to a single branch of the Triad (17–19), the condition is favorably compared to the base case for START. However, force vulnerabilities throughout the Triad, even those partial vulnerabilities assumed for the base case, feed upon each other in a synergistic way (see the simplified example on page 9). If VIT exacerbates these, we face the grave danger that a situation very favorable to the USSR will exist and a breakdown of prevenient stability will occur, as exchanges 20–22 demonstrate.

The last of these, 22, is a troublesome example of a worst-case possibility. We would probably be ill-advised to take the 95% survivability of the Soviet value structure resulting from this simulation at face value, but it is undesirably high and suggests an extremely high Soviet first-strike incentive. The obvious lesson is that, under START, failure to guard against VIT could have disastrous consequences.

Strategic Defense by the US

We have previously examined prevenient stability in the context of strategic defenses protecting US and Soviet value structure for present forces.* The material presented in the next section of Table 7 uses the same general techniques, assuming START forces. The effect of defenses is simulated by reducing the kill-probability data used as input to the code. For example, a 50% effective defense of US value structure means that the kill probabilities for Soviet strike forces against US indices 4, 5, and 6 in Table 6 are cut in half.

Unless otherwise noted, the strategic defenses assumed for this section are effective against Soviet bomber weapons as well as ballistic missiles. This is an important assumption and is discussed later in connection with exchange 32.

Defense of both our strategic forces and value structure should be an important part of strategic defense. As can be seen (simulations 24–26), this type of defense tends to reduce both V and the Soviet first-strike RVFs. It is particularly effective in the case of the defense of air bases. These trends can be considered to be stabilizing and, in addition, they are desirable because they improve the outcome from the US point of view. It is useful to note that defense of strategic air assets is more effective than defense of ICBMs, largely because of the number of bomber weapons located at only a few aimpoints. The fact that exchanges 25 and 26 are so similar has its roots in the discussion on vulnerability and damage limiting in Section II. If US bomber forces are vulnerable, it pays the Soviets to allocate 1000 ballistic reentry vehicles of the SS-18 type in a one-on-one attack of the US Midgetman force, but if bombers are not vulnerable (i.e., all 816 air-delivered nuclear weapons can indeed arrive on Soviet value structure), the damage inflicted by Midgetman is then associated with only the least valuable Soviet assets. Consequently, it is not worth the effort to attack Midgetman.

Two points are worth emphasizing in connection with the defense of strategic strike forces. First, such defense is essentially a nonthreatening action, in that it reduces the value of a Soviet first strike without increasing the incentive for a US first strike. Second, strategic strike forces, particularly bombers, are located in a few, relatively small areas geographically and, from that standpoint, should be more amenable to protection. Both of these points strongly suggest that defense of strategic assets should play a distinct part in any future SDI schemes.

Exchanges 27 through 31 examine the defense of value structure. It is not surprising to see US second-strike RVF values increase with increasing defense effectiveness. And as US residual values increase, V becomes smaller and V' larger. It is in the interest of prevenient stability that the changes in V and V' more or less compensate, so that the sum $V + V'$ remains about the same as in the base case. Of course, as US second-strike RVFs increase due to defense, so do US first-strike RVFs. Therefore, the Soviets

* See Ref. 1. We assumed a randomly subtractive defense of value structure independent of the number of attackers; i.e., one that could not be saturated. We found some instability when both sides had partially effective defenses of their cities. Otherwise, defenses were in the best interests of the US.

would see their deterrent decreasing along with their potential gains from a first strike. On the other hand, Soviet first-strike RVFs remain high no matter how effectively the US value structure is protected. This is a result of the way Soviet optimal first-strike strategies change with US defense effectiveness. To oversimplify, consider a perfect city defense: any Soviet weapons fired in a countervalue role would be wasted. This would not remove all incentive for a Soviet first strike because the counterforce option would still be open, and Soviet strikes against US strategic forces would be useful in reducing damage to the Soviet value structure. This is why RVF_1 (USSR) remains roughly constant as US defense effectiveness ranges from 0 to 100%.

Before moving on to our simulations in the world "Beyond START," we should go back to the assumption that SDI included defense against bombers. A "bomber-leaky" defense could well negate any advantages gained by SDI. This important point is not often stressed, perhaps because we feel that bomber defense is "easy" and bombers are more "stable" than other weapons.[7] The fact of the matter is that neglect of air defense is quite destabilizing and tends to erode the benefits of defense against ballistic missiles. Note that simulation 32 is the least stable of all the simulations of Part III and that US residual assets after a Soviet first strike are only half of what they would have been with assumed effective air defenses.

Beyond START

In Part IV of Table 7, exchanges 33 through 37 explore a few aspects similar to the START simulations of Parts II and III for the case of even deeper cuts in strategic arms; namely another 50% cut in the START forces shown in Table 6. Recall that the US/USSR value structures do not change throughout the tables, so value constitutes an even greater part of the total assets on the two sides. "Beyond START" assumes slightly fewer than 3000 weapons on each side, with value structure remaining at 28,000 points for the USSR and 26,000 for the US.

To first point out the trends resulting from reductions, we review the three base cases (1, 6, and 33). The value V stays remarkably constant, which means that, for a Soviet first strike, the residual assets of the two sides change to compensate. Because there are fewer weapons, both RVFs rise. V' decreases a little because the kill-probability arrays remain the same and because we have assumed a greater counterforce capability on the part of the Soviets. Both sides continue to use counterforce attacks in roughly the same proportion as before, but the Soviets benefit a bit more from such tactics. One notices a little decrease in $V + V'$ in making the comparison, but it is not significant.

The increase in residuals presents a more difficult topic for evaluation. Second-strike RVFs increase as arms are reduced, and it is difficult to argue that this is not a direct benefit of arms reduction. On the other hand, first-strike RVFs also increase, and this does not enhance deterrence as viewed either by the US or the USSR. There is also an imbalance, in that RVF_1 (USSR) is almost twice as large as RVF_1 (US) in exchange 33. This decrease in deterrence is, generally, the fly in the ointment of arms reduction, as we have already seen. Of course, if there were no nuclear weapons, there would be no nuclear deterrent, so the trend we notice is not unexpected nor is it necessarily unacceptable. It is *unpleasant*, however, and hard to deal with.

We next note that defense of value structure has about the same effect beyond START as under START. Defense is very much in the best interests of the US. It does not substantially increase crisis instability, but it does help to even out the disadvantages the US experiences because of the Soviet counterforce offensive edge. At the same time, if we compare the cases for no force vulnerabilities (34 and 16), we find a better world beyond START: crisis stability and a strong deterrent exist simultaneously.

Both simulations 22 and 35 make the worst-case assumption that the US SSBN force is removed from the respective base cases. In simulation 35, we are pleased to see higher second-strike RVFs on both sides. But we face the same quandary as before: the first-strike RVF for both sides also increases, to the detriment of deterrence and prevenient stability. In sum, beyond START is not a striking improvement on START. The same costs and benefits we quantified in passing from the present force structure to START apply to reductions beyond START.

IV. Concluding Remarks

The successful negotiation of a START agreement and its ratification by the US and the USSR is expected to produce a number of benefits, some of which bear on prevenient stability. In a world in which costs and benefits often more or less balance and as the analysis we have just discussed indicates, the absolute "goodness" of arms reduction examined in the context of stability appears to merit a bit more skepticism than accorded in the common wisdom.

To be sure, this paper did not pretend to speak to the advantages that may be derived from START in a political, cultural, or economic sense. Nor should it be taken as an argument pro or con on an agreement that has not yet been codified. Still, as a result of this work, our attention has been drawn to several points that merit the consideration of strategists in the START era. "Merit the consideration" is perhaps too timid an expression. Indeed, great risk will attend the neglect of certain facets of stability that we have examined. For emphasis, we repeat them here.

Because of the large reductions in strategic nuclear weapons it proposes, START would act to decrease the damage done in the event of war. This benefit is not without some subtle cost. As long as vulnerabilities exist in the strategic strike forces of the two sides, the incentive for a first strike will be somewhat more pronounced under START than it is today. The reduction of strategic arms is often taken as the equivalent of a reduction in vulnerability and an increase in prevenient stability. This is not the case. While START does little to damage either prevenient stability or the security of the US, it does nothing to remove the problem of first-strike incentive in the presence of force vulnerability. Indeed, it can have the opposite effect. The reason for concern lies not so much in the lessening of the deterrent as it does in the erroneous belief that arms reductions in some way solve the problem. If this view is and remains dominant in thinking about national defense, future expenditures and tactics needed to maintain survivability may be in jeopardy. That this may be the case should not be construed as an argument against START. Negligence in matters of national defense cannot be attributed to treaties, real or proposed, but rather are indicative of the failure of national will or understanding. Nevertheless, the concern remains.

As a corollary to this point, the subject of VIT is at once troublesome and elusive. Troublesome because we have seen the disastrous consequences that can arise if technology causes unanticipated vulnerabilities, elusive because we are dealing with force structures and technologies that are so far off in the future as to be ill-defined. If anything, reduction in the size of strategic forces tends to increase our concern about this aspect of vulnerability.

With regard to SDI, we noted that the defense of strategic strike forces was important and should perhaps be attended to prior to the defense of other assets. In particular, as long as the US relies on strategic bombers as part of the Triad, defense of their bases is a good option. Moreover, air-base defense increases crisis stability. Insuring the survivability of a large retaliatory force further reduces incentive for the Soviets to make a first strike. Of course, defense of strategic strike forces does nothing to increase other US residual assets after a Soviet first strike; our cities and other centers of value need to be protected for this to be the case. Reductions in numbers of weapons would appear to favor strategic defense of value centers, in that viable schemes need to deal with a lesser threat under START than is the case today. In and of itself, strategic defense of the US value structure does little to change the state of prevenient stability. It does greatly increase the survivability of the US value structure, even under a Soviet first strike. In this connection, we have stressed the importance of bringing air defenses up to the same degree of effectiveness as defense against ballistic missiles. It is an exercise in futility to construct a defense against ballistic missiles and then neglect air defense.

As the new decade begins, it is not entirely fanciful to suggest that the desire for arms reduction will continue to grow so quickly that US and Soviet negotiations will be unable to keep pace. The years beyond START may bring further reductions to strategic arms, perhaps even without benefit of treaty. In short, the step from START to "Beyond START" brings us neither great additional cost nor benefit in terms of stability, but it can result in a situation more readily perturbed by VIT or other factors.

The quandary persists: fewer weapons mean less potential destruction in a nuclear exchange, in itself a highly desirable consequence of arms reduction. However, insofar as increasing residual assets increase the incentive to strike first, deterrence becomes less strong. No clear resolution will be possible unless nuclear weapons are eliminated, complete offensive system invulnerability is achieved, or perfect defenses are developed. All are unlikely. How far, if at all, we proceed along the path of strategic arms reduction will remain a quandary to be resolved by the body politic.

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